CHAPTER 3

Measuring the Chemical Footprint of Plastics

In evaluating the chemical footprint of plastics, the Plastics Scorecard v1.0 differentiates between chemicals used in polymer manufacturing and the final plastic product. Version 1.0 of the Plastics Scorecard measures the chemical footprint of plastics at two levels:

1. Manufacturing: the core chemical inputs used to manufacture a polymer.
2. Product: all chemicals contained in a final, homogeneous, compounded plastic product.

Both the manufacturing data and data on the final homogenous compounded plastic product provide important information on the potential risk to consumers and the environment from the use of certain polymers.

"Chemical footprint" is the measure by number and mass of chemicals of high concern, as determined by hazard level, in products and supply chains. "Hazard level" can be specified using the GreenScreen® benchmarks or an equivalent method. Chemical footprinting is the process of evaluating progress away from chemicals of high concern to human health or the environment to chemicals that have a lower hazard profile than the ones they replace. In this way, a chemical footprint is a measure of the actions an organization takes to advance the development and use of safer chemicals in products and across supply chains.

The following sections first describe the Plastics Scorecard method, then apply that method to two plastic products, IV bags and electronic enclosures, with a comparison of two different plastic materials for each product.

Measuring the Progress to Safer Chemicals in Polymer Manufacturing

The Plastics Scorecard v 1.0 assesses the hazards associated with polymer manufacturing by evaluating the core chemical inputs of the manufacturing process:

- primary chemicals,
- intermediate chemicals, and
- monomers.

For example, in evaluating the manufacture of the polymer, polystyrene, v1.0 assesses the hazards of the following chemicals:

- ethylene and benzene (primary chemicals),
- ethylbenzene (intermediate chemical), and
- styrene (monomer).

The Plastics Scorecard evaluates the hazards posed by each chemical to human health or the environment using the GreenScreen® for Safer Chemicals (see Appendix 2 for details). Version 1.0 of the Scorecard assessed 10 polymers and their core chemical inputs.

The method applied to create the Progress to Safer Chemicals in Polymer Manufacturing Score is as follows:

1. Identify primary chemicals, intermediate chemicals, and monomers by Chemical Abstract Services Registry Number (CAS #) for each polymer. See Appendix 3 for the 10 polymers included in v1.0 and the 28 chemicals used to manufacture those polymers.
2. Evaluate the hazard profile of each chemical. Version 1.0 used two online resources that aggregate chemical hazard data: the Pharos[8] chemical and material library and the Chemical Hazard and Alternatives Toolbox, ChemHAT.[9]
3. Version 1.0 of the Plastics Scorecard adapted the GreenScreen® method to categorize chemicals on a scale of red to green, with "red" being a chemical of high concern to human health or the environment and "green" being a chemical of low concern to human health or the environment. The adapted method is:
   a. Red Chemical: GreenScreen® Benchmark 1 or GreenScreen® Benchmark Possible 1; or chemical for which data are insufficient to perform a hazard assessment.
   b. Orange Chemical: GreenScreen® Benchmark 2 chemical or no hazard data that indicates the chemical is a GreenScreen® Benchmark 1 chemical.
   c. Yellow Chemical: Based on a verified GreenScreen® assessment, the chemical is a GreenScreen® Benchmark 3 chemical.
   d. Green Chemical: Based on a verified GreenScreen® assessment, the chemical is a GreenScreen® Benchmark 4 chemical.
   e. Grey Chemical: Based on a verified GreenScreen® assessment, the chemical is a GreenScreen® Benchmark U (unspecified) chemical.

The Plastics Scorecard assesses the hazards associated with polymer manufacturing by evaluating the core chemical inputs of the manufacturing process: primary chemicals, intermediate chemicals, and monomers.

4. Assign a hazard level to the chemical using the following steps:
   a. First, is the chemical flagged in Pharos as a GreenScreen® Benchmark 1 or GreenScreen® Benchmark Possible 1 chemical?[10] If yes, then flag it as a "red chemical."

8 See Pharos chemical and material library at *http://www.pharosproject.net*.

9 See *www.ChemHAT.org*.

10 Ideally, each chemical would be scored based on full GreenScreen® assessments, i.e., a toxicologist's assessment of the chemical along all 18 hazard endpoints. In the absence of full assessments, the chemicals were assessed with the GreenScreen® List of Lists Translator. The List Translator screens each chemical against authoritative and screening chemical hazard lists to determine whether the chemical is a definitive Benchmark 1 chemical.

   b. Second, if not flagged as red chemical, is there a publicly verified GreenScreen® assessment of the chemical? If yes, apply that benchmark (see Appendix 2).
   c. Third, if no publicly available verified GreenScreen® assessment, consider hiring a licensed GreenScreen® profiler to perform an assessment.
      i. Clean Production Action, for example, hired ToxServices LLC to complete eight GreenSreen® assessments of the chemicals used to manufacture:
         - polyethylene terephthalate (PET): acetic acid, ethylene glycol, terephthalic acid, and bis-(2-hydroxyethyl)-terephthalate;
         - polylactic acid (PLA): glucose, lactic acid, and lactide; and
         - polypropylene: propylene.

         Summaries of these assessments are included in Appendix 2 and the full assessments are available at *www.bizngo.org*.
   d. Fourth, apply the verified GreenScreen® assessment benchmark to the chemicals.
   e. Fifth, for the remaining chemicals, review hazard data to assess whether the chemical might meet the criteria of a chemical of high concern (see definition in Glossary of Terms). If yes, assign chemical as "red chemical", if no, assign chemical as "orange chemical". Appendix 3 lists the 28 chemicals used as a primary chemical, intermediate chemical, and/or monomer in the manufacture of ten different polymers. Of the 28 chemicals, 18 are red chemicals, eight are orange chemicals, one is a yellow chemical, one is a grey chemical, and zero are green chemicals.
5. Aggregate the primary chemicals, intermediate chemicals, and monomers into a single "Progress to Safer Chemicals in Polymer Manufacturing Score." Table 5 summarizes the results of applying this method. The method for scoring polymer manufacturing is as follows:
   a. First, assign a chemical input score for each polymer for each category of chemical inputs (primary chemicals, intermediate chemicals, and monomers). The chemical input score is a ratio of progress to green scaled to 100, divided into a third (such that the algorithm scales to 100 for all three categories of chemical inputs):
      i. Take the chemical inputs for that category (see Appendix 3) and assign a numeric value based on the lowest hazard level score:
         - 0 = red chemical
         - 1 = grey chemical
         - 2 = orange chemical
         - 3 = yellow chemical
         - 4 = green chemical
      ii. Apply the lowest scoring chemical input for that category. If two chemicals, take the lowest scoring chemical. For example, ethylene and chlorine (primary chemical inputs for PVC), where ethylene = 2 and chlorine = 0, take the chorine score of 0.
      iii. Calculate ratio of progress to green: hazard level score divided by 4. A green chemical has a score of 1.00 (4 divided by 4), yellow of 0.75 (3 divided by 4), orange of 0.50 (2 divided by 4), grey of 0.25 (1 divided by 4), and red of 0.00 (0 divided by 4).
      iv. Scale to 100.
      v. Divide by 3; thereby assigning a value of 1/3, 1/3, 1/3 for each manufacturing step of inputs (primary chemicals, intermediate chemicals, and monomers).
   b. Second, add up the score for each step of the manufacturing inputs: Primary Chemicals + Intermediate Chemicals + Monomers = Manufacturing Score.
   c. Third, assign color code to polymer:
      i. Red: Total Manufacturing Score = 0.00
      ii. Orange: Total Manufacturing Score = >0.00 and <34
      iii. Yellow: Total Manufacturing Score = ≥34 and ≤67
      iv. Green: Total Manufacturing Score = >67

What follows are two examples of applying the Progress to Safer Chemicals in Polymer Manufacturing method to PVC and PLA.

Plastics Scorecard

TABLE 5 **Plastics Scorecard: Progress to Safer Chemicals in Polymer Manufacturing**

Polymer	Polymer Manufacturing: Progress to Safer Chemicals Score				Number of Primary Chemicals, Intermediates, and Monomers that are Chemicals of High Concern
	Primary Chemicals	Intermediate Chemicals	Monomer(s)	Total Manufacturing	
Best Case Polymer	33.33	33.33	33.33	100.00	0
Polylactic Acid (PLA)	25.00	16.67	16.67	58.33	0
Polyethylene (PE)	16.67	16.67	16.67	50.00	0
Polypropylene (PP)	16.67	16.67	16.67	50.00	0
Ethylene Vinyl Acetate (EVA)	0.00	16.67	0.00	16.67	2
Polyethylene terephthalate (PET)	0.00	0.00	8.33	8.33	3
Polystyrene (PS)	0.00	0.00	0.00	0.00	3
Polyvinyl Chloride (PVC)	0.00	0.00	0.00	0.00	3
Styrene Butadiene Rubber (SBR)	0.00	0.00	0.00	0.00	4
Acrylonitrile Butadiene Styrene (ABS)	0.00	0.00	0.00	0.00	5
Polycarbonate (PC)	0.00	0.00	0.00	0.00	8

- (Green) The manufacture of the ideal polymer uses green chemicals as defined by GreenScreen® Benchmark 4 in each manufacturing step.
- (Yellow) For each manufacturing step, no core chemical inputs are chemicals of high concern as defined by GreenScreen® Benchmark 1.
- (Orange) Some manufacturing steps include chemicals of high concern as defined by GreenScreen® Benchmark 1, and others do not.
- (Red) Every manufacturing step involves the use of chemicals of high concern as defined by GreenScreen® Benchmark 1.
- (Gray) Manufacturing step involves the use of chemicals determined to be "unspecified" due to the lack of complete hazard data using GreenScreen®.

Notes:
- Only the principal input chemicals are included in this analysis (see Appendix 3).
- For each step, the score is based on the worst performing chemical for human and environmental health. Thus, if any step includes a chemical of high concern, then it receives a zero.
- All steps are considered of equal weight and are scaled to 100—with the green polymer scoring "100" and the red polymer scoring "0".

Scoring Example #1: Scoring the Steps in Polymer Manufacturing for Polyvinyl Chloride (PVC)

1. Primary Chemicals
   - Ethylene = 2
   - Chlorine = 0
   - Primary Chemical Score = sum((0/4)*100)/3 = 0
2. Intermediate Chemical
   - Ethylene Dichloride = 0
   - Intermediate Chemical Score = sum((0/4)*100)/3 = 0
3. Monomer
   - Vinyl Chloride Monomer = 0
   - Monomer Chemical Score = sum((0/4)*100)/3 = 0
4. Total Manufacturing Score for PVC = sum (Primary+Intermediate+Monomer) = 0+0+0 = 0
5. Color Code = Red

Scoring Example #2: Scoring the Steps in Polymer Manufacturing for Polylactic Acid (PLA)

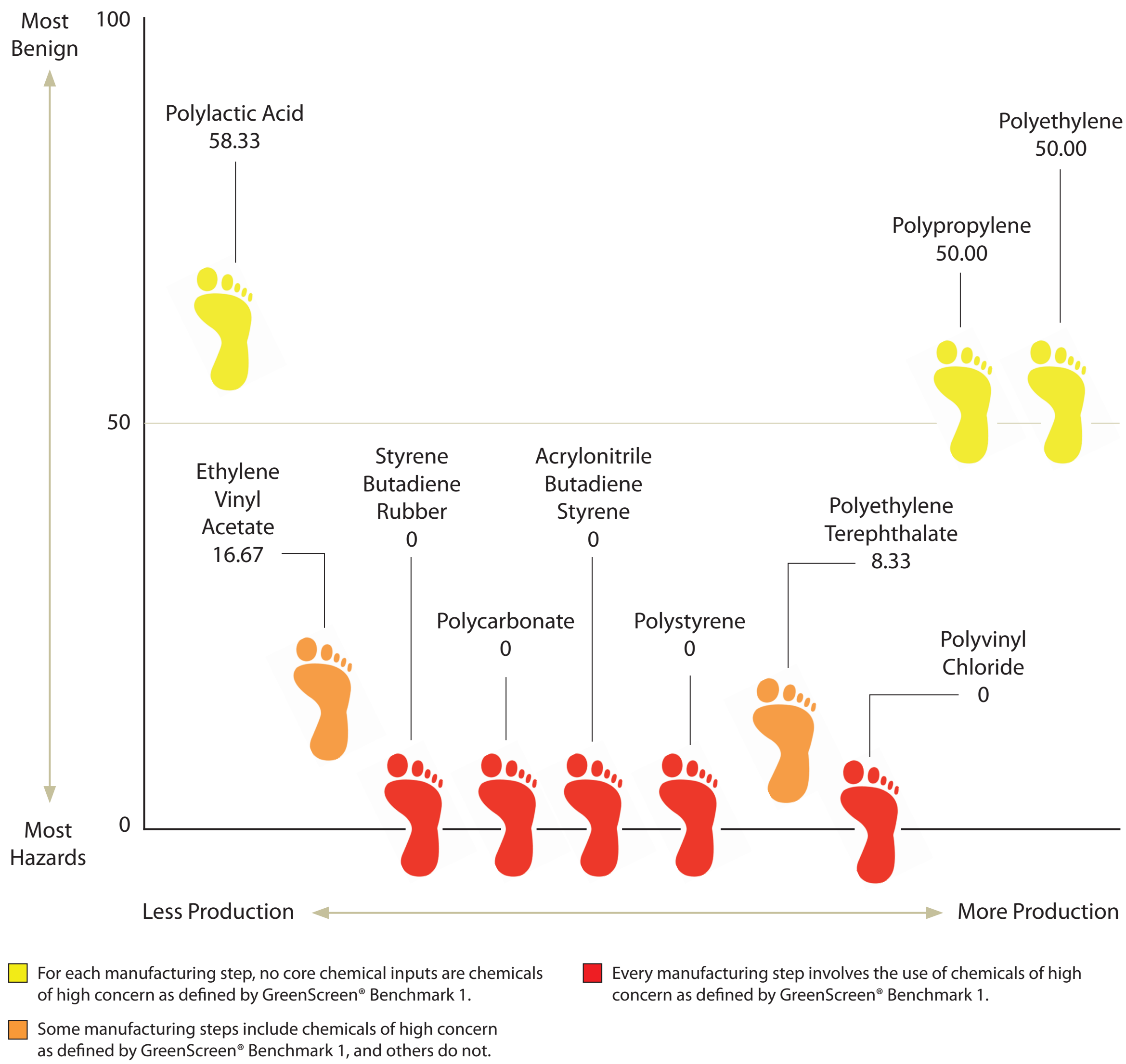
1. Primary Chemicals
   - Glucose = 3
   - Primary Chemical Score = sum((3/4)*100)/3 = 25.00

2. Intermediate Chemical
   - Lactic Acid = 2
   - Intermediate Chemical Score = sum((2/4)*100)/3 = 16.67
3. Monomer
   - Lactide = 2
   - Monomer Chemical Score = sum((2/4)*100)/3 = 16.67
4. Total Manufacturing Score for PLA = sum(Primary+Intermediate+Monomer) = 25+16.67+16.67 = 58.33
5. Color Code = Yellow

Table 5 summarizes the Progress to Safer Chemicals score for 10 polymers. An ideal polymer based on low hazard chemicals would score 100.00. Table 5 reflects the reality that today's polymers are not based on green chemistry. Five of the ten polymers score zero: ABS, PC, PS, PVC, and SBR. That means each stage of manufacturing uses as a primary input a chemical of high concern. PLA, PE, and PP are making the greatest progress to safer chemicals in manufacturing, while EVA and PET are making some progress beyond chemicals of high concern.

Figure 6 graphically illustrates Table 5. On the y-axis is progress to safer chemicals and on the x-axis is volume of production. Thus the polymers that are most widely produced and making the greatest progress to safer chemicals

FIGURE 6 **Progress to Safer Chemicals in Polymer Manufacturing**



are polyethylene and polypropylene. Figure 6 highlights how the vast majority of polymers hover towards the bottom on progress to the safer chemicals. PLA is an emerging polymer that has made significant progress to safer chemicals but is produced in significantly smaller volumes than the other polymers.

Version 1.0 does not address other inputs in the polymer manufacturing process, including catalysts and solvents. The Scorecard focuses on primary chemicals, intermediates, and monomers because they represent the majority of the chemical inputs into polymer manufacturing. The Scorecard can be easily adapted and scaled in the future to address these additional inputs.

Some may contend that primary and intermediate chemicals are of no to little concern to public and environmental health. But as highlighted in Chapter 2, the concerns with workers and local communities and environments being exposed to CoHCs are significant. Certainly a challenge with any polymer manufacturing based on crude oil and natural gas is that those facilities pose their own set of hazards, and it is those facilities that manufacture the primary chemicals from which all polymers are manufactured. Changing the impacts of petroleum and natural gas cracking facilities will require turning to alternative feedstocks and selecting polymers like PLA based on their alternative feedstocks.

Version 1.0 of the Plastics Scorecard also does not consider the raw material feedstocks—for example, crude oil, natural gas, corn, or sugar cane—for the polymer inputs. The Plastics Scorecard v1.0 solely assesses the chemical footprint of manufacturing and final product. It does not integrate raw material feedstocks into the assessment. If a purchaser or designer has concerns with feedstock sources, for example, use of genetically modified organisms (GMOs) in the field or use of food crops for manufacturing plastics, then the purchaser could first screen for those attributes then optimize on chemical footprint. The combination of a drive to more sustainable feedstocks, beyond corn, oil, and gas, and safer chemicals holds the potential for truly market-disruptive polymers.

The Progress to Safer Chemicals in Polymer Manufacturing Score provides a scale for assessing progress to safer chemicals across the steps of polymer manufacturing. It highlights the challenges of and opportunities for moving to inherently safer chemicals in manufacturing, and points to polymers that have made some progress to safer chemicals.

Measuring the Chemical Footprint of a Plastic Product

The Chemical Footprint of a Plastic Product measures the number and weight (or percent weight) of chemicals of high concern in a homogeneous plastic product, be it a component such as a plastic case around a computer monitor or a plastic duck (also known as a rubber ducky). The homogeneous plastic product is a "compounded plastic product" because it includes both the polymer and the additives.

The chemicals in a plastic product include:

- The base **polymer:** by weight, this is the greatest component of the product.
- **Additives:** incorporated into the plastic to enhance product performance. Additives can be a source of CoHCs and may present the relatively easiest opportunity for reducing the chemical footprint of a plastic product. Types of additives include: flame retardants, ultraviolet light (UV) stabilizers, antioxidants, colorants, and plasticizers.

Photo: © Thinkstockphoto/amstockphoto

- **Processing aids:** these are used to facilitate manufacturing processes, including to speed processing times and to easily remove a plastic from molds (including slip agents and lubricants).
- Unreacted or residual **monomer**: In the polymerization of a monomer, there is always some unreacted monomer that becomes lodged in the polymer chain. Over time and under the appropriate conditions—heat, shaking, contact with certain liquids, etc.—the unreacted monomer leaks out of the plastic and leads to human or environmental exposure.
- **Oligomers:** are byproducts of the polymerization process and reside in the polymer at low concentrations.
- Residual **catalysts:** Catalysts speed the rate at which monomers link together during the polymerization process. While manufacturers reclaim and reuse catalysts in the manufacturing process, residual amounts can end up in, and be released from, the polymer while it is in use or during disposal.

Plastic products therefore include both intentionally added chemicals—polymers and additives—as well as unintentionally present chemicals that remain from manufacturing—processing aids, unreacted monomer, residual catalysts, and oligomers. The unintentionally present chemicals are typically on or in the product at small concentrations. The concentration of unreacted monomers and catalyst residuals in polymers is low, typically below 1000 ppm (0.1% by weight) and 100 ppm (0.01%), respectively.

The Chemical Footprint of a Plastic Product is: 1) the total number of CoHCs in the product and 2) the weight (in percentage or actual volume) in the product. The goal is to reduce both the number and weight of CoHCs in a product. Calculating the chemical footprint of a product requires knowing the chemicals in the product. But given that plastics are likely to have chemicals of high concern at very low concentrations (see for example, Jenke, 2002), less than 10 ppm, a key issue is setting the threshold level for knowing chemicals in products. The Plastics Scorecard v 1.0 sets the reporting threshold for intentionally added chemicals at 1000 ppm (0.1% by weight) and for chemicals of high concern at 100 ppm (0.01%). These levels are consistent with the levels required of the U.S. EPA's Design for Environment (DfE) ecolabeling program.

The method for calculating the Chemical Footprint of a Plastic Product is easy to state but difficult to implement:

- Identify the chemicals in the product down to 1000 ppm for intentionally added chemicals.
- Identify which of the intentionally added chemicals are CoHCs. A reference source for identifying CoHCs is the Pharos chemical and material library. Take the list of chemicals in the product and use the Pharos database to identify which chemicals are a GreenScreen® Benchmark 1 or Possible Benchmark 1 chemical.
- Research through suppliers and the technical literature CoHCs likely to be in the plastic product.
- Work with suppliers to disclose CoHCs in the product down to 100 ppm.
- List number of CoHCs in product and percent or volume by weight.

Companies that truly want to measure their progress to safer chemicals will identify CoHCs in their plastic products and the percent weight of these CoHCs, calculate the number of products sold, multiply the weight of CoHCs by number of products sold and thereby know the company's total consumption of CoHCs. That knowledge will enable companies to demonstrate their overall reduced use of CoHCs over time.

From the perspective of potential risk, the primary concern with plastic materials in products is what happens to the chemicals contained in the plastic itself during the product's use and disposal. Will chemicals leak out of the product during use or end of life management—when exposed to sunlight, air, heat or certain types of liquids; or when abraded? And what happens when these chemicals are released into the environment, people and animals—do they breakdown into more toxic byproducts? The best means for preventing the release of CoHCs during use and disposal is to use inherently safer chemicals in the formulation of the product.

The next two sections apply the Chemical Footprint of Plastic Products to two plastic products: 1) intravenous (IV) bags and 2) electronic enclosures.

Chemical Footprint of Plastic Intravenous (IV) Bags

The two IV plastic products evaluated and compared in Plastics Scorecard v1.0 are:

- PVC plasticized with di(2-ethylhexyl) phthalate (DEHP) and
- polyolefin bags made from layers of polyethylene and polypropylene.

PVC/DEHP IV bags dominate the market, although one of the top three producers of IV bags in the U.S.—B Braun—sells primarily polyolefin-based IV bags. As noted in Chapter 2, due to the life cycle concerns with PVC/DEHP IV bags, many hospitals are transitioning to IV bags manufactured without PVC/DEHP. For example, many of the 12 health care systems in the Healthier Hospitals Initiative, which comprise over 490 hospitals with over $20 billion in purchasing power, are taking the Safer Chemicals Challenge to reduce PVC/DEHP products used in health care.[11]

Key sources used to estimate the number and percent weight of CoHCs in PVC/DEHP and polyolefin bags data were:

- Jenke (2002), article on "Extractable/Leachable Substances from Plastic Materials Used as Pharmaceutical Product Containers/Devices", which reviews the literature on the chemicals extracted and leached from plastic materials used in health care, including PVC with DEHP and polyolefins;

From the perspective of potential risk, the primary concern with plastic materials in products is what happens to the chemicals contained in the plastic itself during the product's use and disposal.

- European Commission (2007) *Preliminary Report on the Safety of Medical Devices Containing DEHP Plasticized PVC or Other Plasticizers on Neonates and Other Groups Possibly At Risk*;
- Danish Technological Institute (2013) report on *Hazardous Substances in Plastic Materials*; and
- Ed Phillips, Basell Polyolefins (Phillips, 2001) presentation on additives in polyolefin laminates used in health care.

Overall the most definitive data points on chemicals in IV bags as a percent by weight were from:

- The European Commission (2007), which stated that:
  - DEHP is added to PVC as a plasticizer at 30% by weight.
  - BPA is added as antioxidant at 0.5% by weight.
- Phillips (2001) presentation that listed additives and their percent level found in polyolefin IV bags.

11 See *http://healthierhospitals.org/hhi-challenges/safer-chemicals.*

TABLE 6 **Plastic Intravenous (IV) Bag**

Estimated Chemical Footprint of Polyvinyl Chloride (PVC) Plasticized with Di(2-Ethylhexyl) Phthalate (DEHP)

Functional Use: Chemical Ingredients	Weight (%)	Chemicals of High Concern (CoHCs)	
		Chemicals	%
Polymer: PVC[1]	68.80%	*	*
Plasticizer: DEHP[2]	30.00%	DEHP	30.00%
Antioxidants: including Bisphenol A (BPA)[3]	0.50%	BPA	0.50%
Heat stabilizers[4]	0.50%	unknown	unknown
Lubricants[5]	0.10%	unknown	unknown
Slip Agents[6]	0.10%	unknown	unknown
Monomers and oligomers—residual: vinyl chloride monomer (VCM)[7]	0.0001%	VCM	0.0001%
Solvent—residual[8]	unknown	unknown	unknown
Catalyst—residual	unknown	unknown	unknown
Total	**100.00%**	**at least 3**	**30.50%**

Chemical is a chemical of high concern

Unknown whether chemicals of high concern from that functional use are present

* Polymers are generally considered to be of low concern to human health and the environment (European Commission 2012b). This product assessment of polymer hazard excludes other life cycle hazards, including manufacturing and end of life management.

Sources of Weight: 1. Estimated, 2. European Commission, 2007, 3. European Commission, 2007, 4. Danish Technological Institute, 2013, 5. Danish Technological Institute, 2013, 6. Danish Technological Institute, 2013, 7. Jenke, 2002; European Pharmacopoeia, 2005, 8. Jenke, 2002,

In addition, the Danish Technological Institute report provided generic data points on additives and likely concentrations in specific polymers. And the Jenke, 2002 article listed confirmed chemicals found in PVC and polyolefin extraction studies.

Tables 6 and 7 list the functional uses of chemicals in the IV plastic products (for example, plasticizer); when known, the specific chemical used (for example, DEHP as a plasticizer); the estimated weight of the chemical in the product; and whether or not the chemical is a known CoHC.

Key results from Tables 6 and 7 include:

- DEHP makes up a significant percentage of the PVC IV bag because plasticizers are necessary to make PVC flexible. Polyolefins are naturally flexible and to the extent they use plasticizers, use them at much lower levels. For example, Basell Polyolefins reported using plasticizers at 0.003% (30 ppm) (Phillips, 2001).
- Unreacted monomers will be at very low levels for medical grade polymers because they are closely regulated.
- Knowledge gaps: the specific chemicals (for example, by CAS #) used as additives is not readily available. For example, researchers and technical experts know in general that PVC products contain heat stabilizers, but the specific heat stabilizers used in a specific product is difficult to ascertain.

Figure 7 illustrates the benefits of substituting PVC/DEHP with polyolefins for plastic IV bags. Polyolefin polymers (polypropylene and polyethylene) score much higher, 50.0, on the Plastics Scorecard's "progress to safer chemicals score"

TABLE 7 Plastic Intravenous (IV) Bag

Estimated Chemical Footprint of Composite Polyolefin Product

Functional Use: Chemical Ingredients	Weight (%)	Chemicals of High Concern (CoHCs)	
		Chemicals	%
Polymer: Composite of Polyolefin / Polypropylene[1]	99.39%	*	*
Antioxidants	0.20%	unknown	unknown
Hindered phenols[2]	0.10%	unknown	unknown
Phosphates[3]	0.10%	unknown	unknown
Antacids: Stearates[4]	0.10%	unknown	unknown
Lubricants[5]	0.10%	unknown	unknown
Slip agents[6]	0.10%	unknown	unknown
Peroxide[7]	0.09%	unknown	unknown
Catalyst—residual[8]	0.015%	unknown	unknown
Plasticizer: phthalates[9]	0.003%	unknown	unknown
Monomers and oligomers—residual[10]	unknown	unknown	unknown
Solvent—residual[11]	unknown	unknown	unknown
Adhesive: urethane-based[12]	unknown	unknown	unknown
Total	**100.00%**	**best possible scenario—0**	**0.00%**

Chemical is a chemical of high concern

Unknown whether chemicals of high concern from that functional use are present

* Polymers are generally considered to be of low concern to human health and the environment (European Commission 2012b). This product assessment of polymer hazard excludes other life cycle hazards, including manufacturing and end of life management.

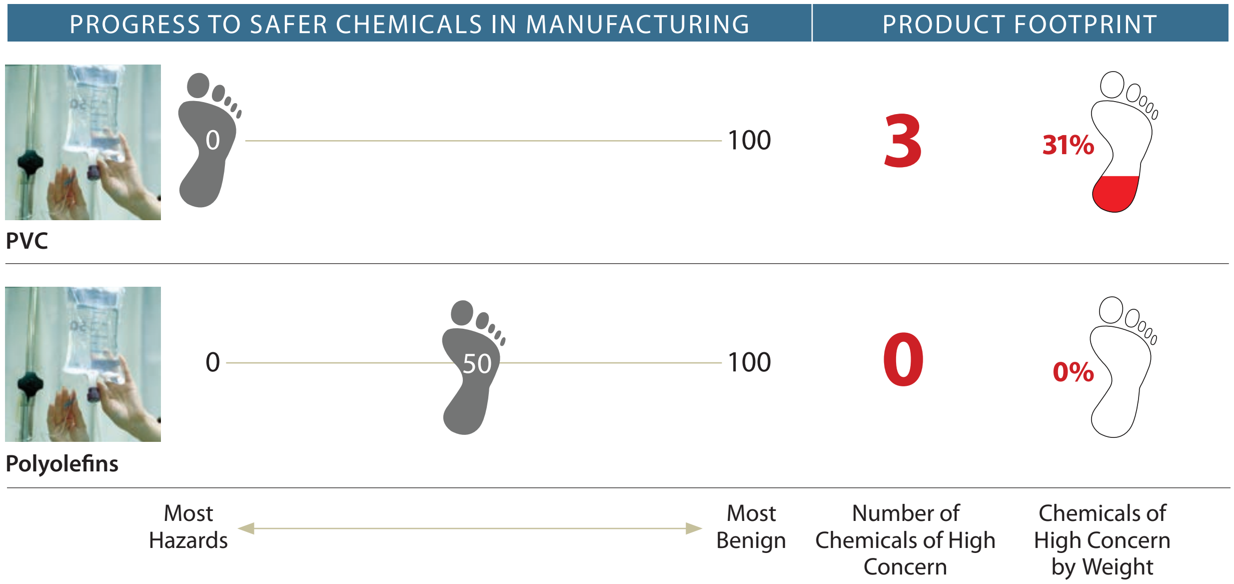
Sources of weight: 1. Estimated, 2. Basell Polyolefins, 2001, 3. Basell Polyolefins, 2001, 4. Basell Polyolefins, 2001, 5. Jenke, 2002; Danish Technological Institute, 2013, 6. Danish Technological Institute, 2013, 7. Basell Polyolefins, 2001, 8. Basell Polyolefins, 2001, 9. Jenke, 2002; Basell Polyolefins, 2001, 10. Jenke, 2002, 11. Jenke, 2002, 12. Jenke, 2002

than PVC, which scores 0.0. In addition, the polyolefin bags greatly reduce the chemical footprint of the products. The PVC/DEHP IV bags contain a significant percentage of CoHCs, 30% DEHP and 0.5% BPA by weight, in comparison to the estimated 0% by weight for polyolefins. But even if all the polyolefin additives were CoHCs, the percent CoHCs would only be 0.61% in the polyolefin bags. Thus switching from PVC/DEHP bags presents a significant opportunity to reduce the percentage of CoHCs in IV bags by approximately 30% by weight.

Dignity Health's (formerly Catholic Healthcare West) switch from PVC/DEHP IV bags to B Braun's polyolefin-based product in 2008 demonstrates the reduced chemical footprint of polyolefin IV bags. Over the six year period from 2008 to 2013, Dignity Health reduced the chemical footprint of its IV bags by:

- Eliminating 1,543,467 pounds of PVC polymer (excludes additives):
    - PVC as a polymer scores "0," whereas the polyolefins (polypropylene and polyethylene)

FIGURE 7 **Chemical Footprint of IV Bags Made from PVC/DEHP & Polyolefins**



PVC = Polyvinyl chloride; DEHP = di(2-ethylhexyl) phthalate

Collecting data on the chemical ingredients in electronic enclosures involved combing through a variety of resources. Studies on the flame retardants in electronic enclosures and their hazards were particularly helpful in specifying both the chemicals and their percent concentration.

score 50.0, on the Plastic Scorecard's progress to safer chemicals scale (the higher the score the more preferable the product is for the environment and human health).

- Reducing Chemicals of High Concern:
  - Eliminated 673,023 pounds of DEHP.
  - Eliminated 33,651 pounds of BPA.[12]

Chemical Footprint of Plastic Electronic Enclosures

"Electronic enclosures" are the plastic housings surrounding an electronic product, such as a television (TV), computer monitor, or laptop. Manufacturers add flame retardants to plastic enclosures because the materials are flammable and exposed to heat during use. Amid growing concerns of the flame retardants leaking out of the plastics, in particular decabromodiphenyl ether (decaBDE), regulators in Europe and in states like Maine and Washington, took action in the 2000's to restrict the use of decaBDE. In anticipation of the regulations, manufacturers searched about for alternatives, with some choosing to continue with other brominated flame retardants while others opted to eliminate all brominated and chlorinated flame retardants. The movement away from decaBDE and other brominated flame retardants in electronic enclosures also led to the search for alternative plastics. High Impact Polystyrene (HIPS), a relatively inexpensive polymer, flame retarded with decaBDE or another brominated flame retardant dominated the market because it was an effective and low cost solution to housing electronic devices.

As manufacturers searched for non-brominated and non-chlorinated flame retardants, they discovered that the alternative flame retardants required alternative polymers. Polycarbonate (PC)/Acrylonitrile Butadiene Styrene (ABS) polymers with phosphorous-based flame retardants

12 Calculated reductions in PVC, DEHP, and BPA based on estimate of reduced PVC material use in Kudzia, et al., 2008.

emerged as the most popular non-halogenated solution to HIPS with decaBDE enclosures. This transition away from HIPS/decaBDE to PC/ABS with RDP provides a good case study for assessing whether manufacturers made a regrettable substitution—substituting known CoHCs with unknown alternatives that are later found to also be a chemical of high concern.

Collecting data on the chemical ingredients in electronic enclosures involved combing through a variety of resources. Studies on the flame retardants in electronic enclosures and their hazards were particular helpful in specifying both the chemicals and their percent concentration, including:

- Lowell Center for Sustainable Production (LCSP, 2005) report on *Decabromodiphenylether* and
- Washington State Department of Ecology (2008) report on Alternatives to DecaBDE.

In terms of other additives contained in HIPS and PC/ABS products a range of resources were particularly helpful in specifying percent concentrations and/or specific chemicals, including:

- Danish Technological Institute (2013) report on Hazardous Substances in Plastic Materials and
- Jenke (2002) article on extractable and leachable chemicals in plastic materials used in health care products.

Industry resources were helpful in specifying concentrations of co-polymers in the products, including:

- International Institute of Synthetic Rubber Producers on concentration of polybutadiene in HIPS and
- CEFIC (2014) summary on chemistries of electronics enclosures on percent of ABS in PC/ABS polymers.

Finally a variety of articles beyond those mentioned above were helpful to understanding residual monomers in products, mostly notably

Photo: © Getty Images News/Mario Tama

TABLE 8 **Plastic Electronic Enclosure**

Estimated Chemical Footprint of High Impact Polystyrene (HIPS) with Decabromodiphenyl Ether (DecaBDE) Flame Retardant

Functional Use: Chemical Ingredients	Weight (%)*	Chemicals of High Concern (CoHCs)	
		Chemicals	%
Polymer: Polystyrene[1]	73.55%	*	*
Flame Retardant:	16.00%		
DecaBDE[2]	11.64%	DecaBDE	11.64%
Nonabromodiphenyl ether[3]	0.36%	NonaBDE	0.36%
Antimony trioxide[4]	4.00%	Antimony trioxide	4.00%
Polymer: Polybutadiene[5]	7.00%	not of high concern	not of high concern
Antioxidants, Processing Stabilizers, and UV Stabilizers[6]	3.00%	unknown	unknown
Lubricants and slip agents[7]	0.20%	unknown	unknown
Monomers and oligomers—residuals: includes styrene and butadiene[8]	0.15%	Styrene, Butadiene	0.15%
Antistatic agents[9]	0.10%	unknown	unknown
Colorants[10]	unknown	unknown	unknown
Catalysts: residual	unknown	unknown	unknown
Total	**100.00%**	**at least 5**	**16.15%**

Chemical is a chemical of high concern
Unknown whether chemicals of high concern from that functional use are present

* Polymers are generally considered to be of low concern to human health and the environment (European Commission 2012b). This product assessment of polymer hazard excludes other life cycle hazards, including manufacturing and end of life management.

Sources of Weight: 1. Estimated, 2. LCSP, 2005; WA State 2008, 3. LCSP, 2005, 4. LCSP, 2005, 5. IISRP, 2014, 6. Danish Technological Institute, 2013; Jenke 2002, 7. Danish Technological Institute, 2013; Jenke 2002, 8. Araujo, et al, 2002; Jenke 2002, 9. Danish Technological Institute, 2013; Smith, 1998, 10. Danish Technological Institute 2013

the research by Araújo, et al. (2002) on residual monomer content in polymers.

Tables 8 and 9 list the functional uses of chemicals in plastic electronics enclosures; when known, the specific chemical used (for example, the specific chemicals contained in RDP formulations for flame retarding PC/ABS); the estimated weight of the chemical in the product; and whether or not the chemical is a known CoHC.

Key results from Tables 8 and 9 include:

- Residual **monomers:** The presence of residual monomers in plastic products is well documented and research and development into methods for reducing residual monomers is a well-developed field of activity. Yet what is not known is what levels of residual monomer are generally found in a class of products like electronic enclosures. Manufacturing

Plastics Scorecard

TABLE 9 **Plastic Electronic Enclosure**

Estimated Chemical Footprint of Polycarbonate (PC) / Acrylonitrile Butadiene Styrene (ABS) with Resorcinol bis(diphenylphosphate) (RDP) Flame Retardant

Functional Use: Chemical Ingredients	Weight (%)	Chemicals of High Concern (CoHCs)	
		Chemicals	**%**
Polymer: Polycarbonate[1]	51.45%	*	*
Polymer: ABS[2]	25.00%	*	*
Flame Retardant: RDP constituents[3]	20.00%		
Phosphoric acid, 1,3-phenylene tetraphenyl ester (CAS# 57583-54-7)[4]	14.50%	not of high concern	not of high concern
Phosphoric acid, bis[3-[(diphenoxyphosphinyl)oxy] phenyl] phenyl ester (CAS# 98165-92-5)[5]	4.50%	not of high concern	not of high concern
Triphenyl phosphate (CAS# 115-86-6)[6]	1.00%	Triphenyl Phosphate	1.00%
Antioxidants, Processing Stabilizers, and UV Stabilizers[7]	3.00%	unknown	unknown
Drip resistance: Polytetrafluoroethylene[8]	0.30%	unknown	unknown
Monomers and oligomers: residuals[9]	0.25%	Bisphenol A, Acyrlonitrile, Butadiene, Styrene	0.25%
Antistatic agents[10]	0.10%	unknown	unknown
Colorants[11]	unknown	unknown	unknown
Catalysts: residual	unknown	unknown	unknown
Total	**100.00%**	**at least 5**	**1.25%**

Chemical is a chemical of high concern
Unknown whether chemicals of high concern from that functional use are present

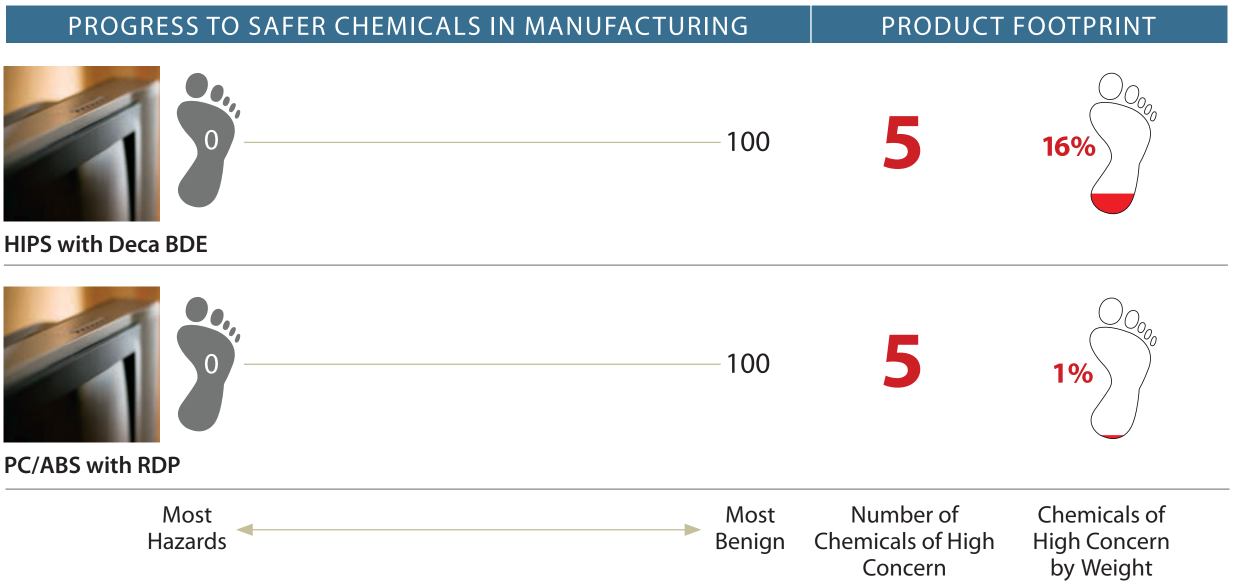
* Polymers are generally considered to be of low concern to human health and the environment (European Commission 2012b).
This product assessment of polymer hazard excludes other life cycle hazards, including manufacturing and end of life management.

Sources of Weight: 1. Estimated, 2. Cefic, 2014, 3. Washington State, 2008, 4. Washington State, 2008, 5. Washington State, 2008, 6. Washington State, 2008, 7. Danish Technological Institute, 2013; Jenke 2002, 8. Lowell Center for Sustainable Production, 2005, 9. Jenke 2002; Danish Technological Institute, 2013; Choi and Kim, 2012; Araujo, et al., 2002; REACH, 2012, 10. Danish Technological Institute 2013, 11. Danish Technological Institute 2013

practices clearly determine levels of residual monomers. Given the uncertainty about residual monomers in product, however, the preventive solution is to avoid monomers that are CoHCs.

- Residual **catalysts:** Like residual monomers, researchers in polymeric chemistry know that residual catalysts are present in the product. But again similar to residual monomers, they are at low levels and their presence will vary with manufacturing processes.
- Knowledge gaps in **additives:** As with the IV bag comparison in the preceding section, data are sparse on the specific chemicals used in the more obscure additive functions. Public knowledge on additives is greatest and most accurate where the spotlight of public attention focuses. In the case of electronic enclosures, that is on flame retardant additives, where researchers learned the specific chemical additives in flame retardant formulations and their concentrations.

FIGURE 8 **Chemical Footprint of Electronic Enclosures Made from High Impact Polystyrene (HIPS) with DecaBDE & PC/ABS with RDP**



ABS = Acrylonitrile Butadiene Styrene; DecaBDE = Decabromodiphenyl Ether; PC = Polycarbonate; RDP = Resorcinol Diphenylphosphate

Figure 8 illustrates the benefits of substituting a HIPS with DecaBDE enclosure with a PC/ABS with RDP enclosure. At the product level the PC/ABS enclosure reduces the volume of CoHCs from 16% to 1% by weight of product. The key actor in the beneficial result is the elimination of the CoHC, decaBDE, and its replacement with RDP. While RDP is by no means a green flame retardant, its ingredients overall are less hazardous than decaBDE. The electronic enclosures story is one where the opportunities to green the final product are fairly limited. Given price and performance needs, PC/ABS is the most effective solution. While the volume of CoHCs decline with the use of RDP, the number of CoHCs in the product remains unchanged. Similarly, the progress to safer chemicals in manufacturing score remains at 0.0.

Is PC/ABS with RDP a regrettable substitution for HIPS/ decaBDE? The above data indicate it is not, and at the aggregate level it results in significant reductions in CoHCs by percent weight. Yet there are many unknowns. The science on the health effects of phosphorous-based chemistry continues to develop; unknown health hazards may arise with this chemistry. At the same time, the small amounts of unknown additives as well as the residual monomers (like BPA) may prove to be problematic in the future. It is clear PC/ABS with RDP is a less bad solution, but it is hardly an optimal solution. The ideal plastic is a safer polymer with additives of low concern to humans and the environment.